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Willingness to pay for renewable energy investment in Korea: A choice experiment study

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ABSTRACT

Renewable energy sources are considered as alternatives for coping with the high price of oil and global warming. The Korean government has set a target that 11% of the total primary energy supply should be obtained through renewable energy sources until 2030. In order to develop proper policies for renewable energy investment, it is necessary to analyze the benefits of renewable energy investment based on households' willingness to pay. This study attempts to apply a choice experiment (CE) for assessing renewable energy investment in Korea. Moreover, we employ a multinomial probit (MNP) model to relax the assumption that all respondents have the same preferences for the attributes being valued, which is usually required in empirical CE studies. An MNP model allows the most flexible pattern of error correlation structure. The results reveal that the Korean public puts a value on the protection of wildlife, reduction of pollution, and increased employment opportunities. On the other hand, respondents do not derive significant values from the improvement of landscapes. This study is expected to provide policy-makers with useful information for evaluating and planning policies related to renewable energy investment.

Contents

1. Introduction

The average temperature on earth has risen by about 0.5 °C over the past 100 years. The main reason for global warming is carbon dioxide that is emitted through the consumption of fossil-fuels. The excessive use of fossil-fuel has caused the greenhouse-gas effect. According to the International Panel on Climate Change [1], the average temperature on earth is predicted to increase by between 0.8 °C and 3.5 °C by 2100 if carbon dioxide reduction policies are not implemented urgently. Moreover, fossil energy resources, which mainly include coal, oil, and natural gas, are getting gradually depleted and the demand for energy has dramatically increased in developing countries, such as China

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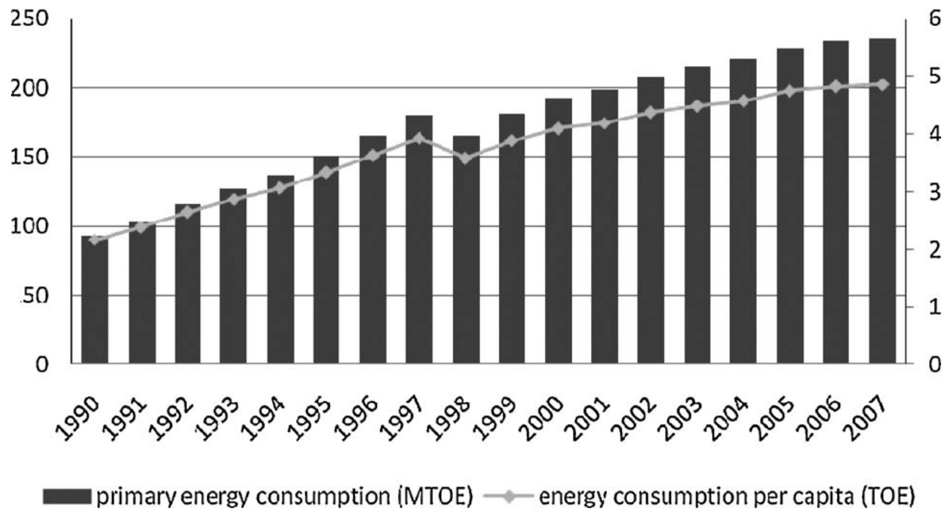

Fig. 1. Primary energy consumption in Korea.Source: Korea Energy Economics Institute (available at: http://www.keei.re.kr).

and India. This worsening situation, along with unstable trends on oil prices in the world market, is expected to cause severe competition among countries to secure more energy.

Therefore, many countries have an interest in renewable energy development for securing a sustainable supply of energy and are strongly pursuing renewable energy legislation, incentives, and commercialization with the development of renewable energy technology. For example, in March 2007, European Union (EU) leaders reached an agreement in principle that 20% of the EU nations' energy should be produced from renewable energy by 2020 as part of the EU's collective drive to cut emissions of carbon dioxide that are blamed for global warming.

Numerous studies have been conducted on renewable energy sources. For an overview of previous studies, see Table 1 given in [2,3]. We can discern studies on the valuation of diverse renewable energies in various countries and areas. However, thus far, little research has focused on households' willingness to pay (WTP) for Korean renewable energy investment even though Korea is one of the countries where the growth rate of energy demand is quite high and alternative sources of energy are scarce.

This study attempts to apply a choice experiment (CE) to assess renewable energy investment in Korea by considering various attributes. While most previous discrete choice models have the multinomial logit (MNL) form, this study employs a multinomial probit (MNP) model. Although MNL has an advantage in that the choice probability has a simple closed form, it has a serious drawback, which is known as the 'independence from irrelevant alternatives' (IIA) property. To overcome this problem, other advanced approaches can be considered, such as a generalized extreme value model [4], a heteroskedastic extreme value model [5], and an MNP model. Among them, the MNP model is the most appealing because it allows the most flexible pattern of error correlation structure. This approach allows us to relax the assumption that all respondents have the same preferences for the attributes being valued. The ability to model unobservable heterogeneous preferences in the population is a clear advantage of this technique [6].

The message of this paper is all the more useful because the valuation of renewable energy investment in Korea is first done using the CE approach and the MNP model is first applied in the CE study for renewable energy investment. The remainder of the paper is organized as follows: Section 2 explains the current status of energy in Korea. Section 3 reviews the CE and its methodological issues. Section 4 presents statistical models for deriving the WTP for renewable energy investment. Section 5 contains the results of the study. Some concluding remarks are made in the final section.

2. The current status of energy in Korea

According to BP [7], the energy consumption in Korea was 227 MTOE in 2006, which was the 9th highest in the world. In particular, oil consumption is ranked the 7th in the world. Fig. 1 shows the level of energy consumption in Korea. The total primary energy consumption and the energy consumption per capita have steadily increased since 2000; they were 236 MTOE and 4.86 TOE in 2007, respectively. Fig. 2 shows the evolution of the total primary energy consumption from 1980 to 2007. Compared with other energy sources, the share of renewable energy has been and continues to be very low. Although renewable energy sources are considered as alternatives for coping with the high price of oil and global warming, they account for only 2% of the total energy supply in Korea.

In developed countries, renewable energy accounts for a higher proportion in the energy supply mixture: 10.4% in Denmark; 7% in France; and 4.3% in the US. The Korean government has set a target that 11% of the total primary energy supply would be obtained by renewable energy sources by 2030. Currently, the government has various measures for supporting renewable energy development, including a feed-in tariff, tax benefits, and funding for research and development (R&D). According to the Korea Energy Management Cooperation, between 1988 and 2007, the government and the private sector invested 560 billion Korean won (USD 583 million) and 358 billion Korean won (USD 373 million), respectively, in R&D for renewable energy.

3. The choice experiment

The CE approach offers a promising opportunity for measuring the various economic values of renewable energy sources, since it is concerned with modeling choices that vary over a range of characteristics rather than with the estimation of the WTP for a single option. We identified the following four attributes: landscape, wildlife, air pollution, and employment. Table 1 describes these attributes, as well as the price attribute, and how each level of attributes is defined.

CE involves the use of statistical design theory to construct choice sets that can yield coefficient estimates that are not confounded by other factors [8]. In this study, we employed the

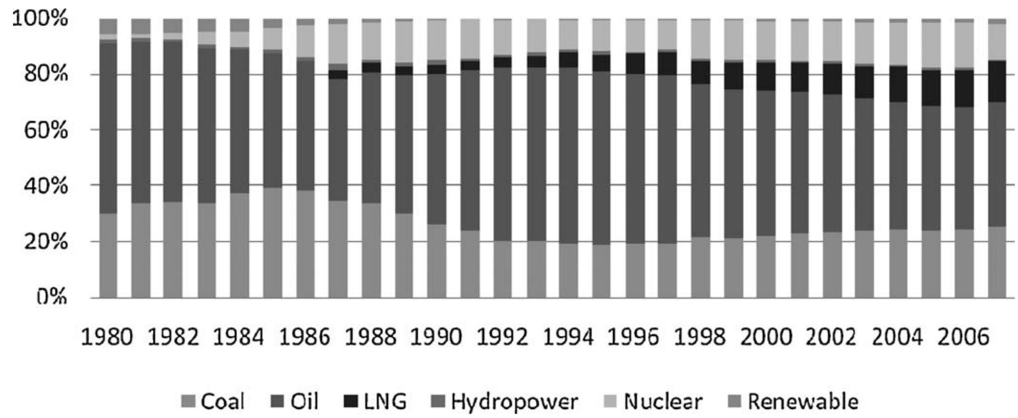

Fig. 2. Evolution of the total primary energy consumption in Korea.Source: Korea Energy Economics Institute (available at: http://www.keei.re.kr).

Table 1
Descriptions and levels of the chosen attributes.

Attribute	Description	Levels
Landscape	The effect of improvement in the landscape from the renewable energy plant compared to a fossil-fuel power plant (unit: %)	Level 1: 0[a] Level 2: 25% Level 3: 50%
Wildlife	The effect of improvement in the diversity of species living in the vicinity of the renewable energy plant compared to a fossil-fuel power plant (unit: %)	Level 1: 0[a] Level 2: 25% Level 3: 50%
Air pollution	The effect of a decrease in air pollution from the renewable energy plant compared to a fossil-fuel power plant (unit: %)	Level 1: 0[a] Level 2: 70% Level 3: 100%
Employment	The number of new, local, long-term employment opportunities compared to a fossil-fuel power plant (unit: persons)	Level 1: 0[a] Level 2: 10 Level 3: 30
Price	Monthly increase in household electric charges resulting from the expansion of renewable energy projects (unit: Korean won)	Level 1: 0[a] Level 2: 1,000 Level 3: 2,000 Level 4: 4,000 Level 5: 7,000

[a] Indicates the level of the effect from a fossil-fuel power plant.

'orthogonal main effects design,' which is effective in terms of isolating the effects of individual attributes on the choice. The ability to 'design in' this orthogonality is an important advantage over revealed preference random utility models, where, in reality, attributes are often found to be highly correlated with one another [9]. The orthogonal main effects design was implemented by using the SPSS 12.0 package [10].

In the CE questions, there were three alternatives of which two represented renewable energy investment featuring combinations of attribute levels and specific price levels. The third alternative

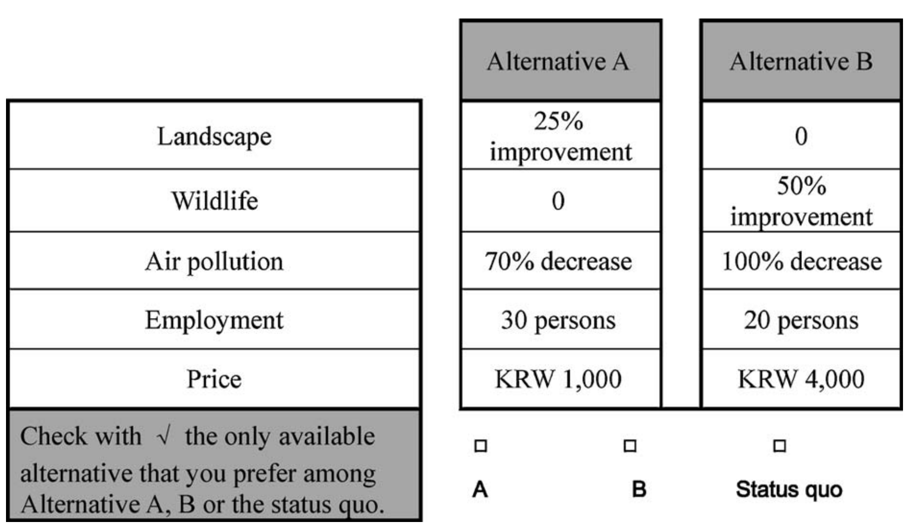

Fig. 3. A sample choice set used in this study.

represented the status quo. Then, there were $3^8 \times 5^2$ possible combinations of attributes and levels for forming the choice sets. Since it was impractical to ask respondents to choose from all combinations, we drew a subset of all choice sets for estimating coefficients and drew 36 choice sets. They were then randomly divided into six sets of 6 choices each. Fig. 3 presents an example of a choice set that was actually used. Each respondent was presented with six choice sets and was asked to choose among the status quo and two alternatives.

The survey questionnaire comprised three sections. The first part was intended to measure respondents' general recognition of renewable energy to familiarize them with the attributes of renewable energy sources being evaluated. To enhance respondents' understanding, a color photograph of renewable energy, such as solar heat power and wind power, was inserted in this section. The second part contained questions for CE analysis that were designed to elicit respondents' WTP for renewable energy investment by estimating trade-offs between price and other attributes. The final part elicited socio-economic information on the respondents, such as income, age, and education.

We conducted 800 person-to-person interviews. The survey was carried out in the metropolitan areas (Seoul, Incheon, and Gyeonggi). Owing to a budget constraint, we could not cover the whole country for the survey. However, it was thought that the metropolitan areas, including Seoul, the capital of Korea, could represent the whole country since a half of the total population lives there. Sampling and field work were done by interview experts of a professional polling firm, Dongseo Research, Inc., which is located in Seoul. The interviews were done on randomly selected respondents to maximize the scope for detailed questions and answers.

4. Model

4.1. Multinomial probit model

In this study, the random utility model is used to explain individual choices by specifying functions for the utility that is derived from the available alternatives. The indirect utility function for each respondent i, who chooses alternative j in the choice set, can be expressed as:

$$U_{ij} = V_{ij}(X_{ij}) + e_{ij}. \tag{1}$$

The indirect utility function, U_{ij}, can be decomposed into a deterministic part, V_{ij}, which is typically specified as a function of the attributes X_{ij} in alternative j chosen by respondent i, and a stochastic part, e_{ij}, which represents the unobservable influence on the individual i's choice of alternative j.

An MNP model assumes that the errors, e_{ij}, follow a multivariate normal distribution with a mean-vector of zero and a covariance matrix defined as:

$$\Omega = \begin{bmatrix} \sigma_1^2 & \sigma_{12} & \sigma_{13} \\ \sigma_{12} & \sigma_2^2 & \sigma_{23} \\ \sigma_{13} & \sigma_{23} & \sigma_3^2 \end{bmatrix}. \tag{2}$$

Consider the probability that the first alternative will be chosen.

$$\begin{aligned} Pr(U_{i1} > U_{i2}, U_{i1} > U_{i3}) &= Pr(e_{i2} - e_{i1} < V_{i1} - V_{i2}, e_{i3} - e_{i1} < V_{i1} - V_{i3}) \\ &= Pr(\eta_{21} < V_{12}, \eta_{31} < V_{13}) \\ &= \int_{-\infty}^{V_{12}} \int_{-\infty}^{V_{13}} f(\eta_{21}, \eta_{31}) d\eta_{21} d\eta_{31}, \end{aligned} \tag{3}$$

where $\eta_{21} = e_{i2} - e_{i1}$, $\eta_{31} = e_{i3} - e_{i1}$, $V_{12} = V_{i1} - V_{i2}$, and $V_{13} = V_{i1} - V_{i3}$. $f(\eta_{21}, \eta_{31})$ has a bivariate normal distribution with covariance matrix, Ω_1, which is transformed from Ω. We can identify the first diagonal element of the covariance matrix to one to add a property that scale shift would not change the observed choices. Ω_1 is given by:

$$\begin{aligned} \Omega_1 &= \begin{bmatrix} \sigma_1^2 + \sigma_2^2 - 2\sigma_{12} & \sigma_1^2 - \sigma_{13} - \sigma_{12} + \sigma_{23} \\ \sigma_1^2 - \sigma_{13} - \sigma_{12} + \sigma_{23} & \sigma_1^2 + \sigma_3^2 - 2\sigma_{13} \end{bmatrix} \\ &= \begin{bmatrix} 1 & \theta_{23} \\ \theta_{23} & \theta_{33} \end{bmatrix}, \end{aligned} \tag{4}$$

where $\theta_{23} = (\sigma_1^2 - \sigma_{13} - \sigma_{12} + \sigma_{23})/(\sigma_1^2 + \sigma_2^2 - 2\sigma_{12})$ and $\theta_{33} = (\sigma_1^2 + \sigma_3^2 - 2\sigma_{13})/(\sigma_1^2 + \sigma_2^2 - 2\sigma_{12})$.

The probabilities that the second and third alternatives will be chosen can be similarly derived [11].

4.2. The utility function and marginal WTP

The utility function of the model, with the exception of the error term, can be expressed as a linear function of an attribute vector $(Z_1, Z_2, Z_3, Z_4, Z_5)$ = (Landscape, Wildlife, Air pollution, Employment, and Price). We include two alternative-specific constants (ASCs), which represent dummies for the respondent's choosing alternatives A and B in the choice set. The ASCs capture the utilities of alternatives that the attributes fail to capture [12].

$$V_{ij} = \mathrm{ASC}_j + \beta_1 Z_{1,ij} + \beta_2 Z_{2,ij} + \beta_3 Z_{3,ij} + \beta_4 Z_{4,ij} + \beta_5 Z_{5,ij}. \tag{5}$$

In Eq. (5), the βs are the parameters to be estimated for each attribute that influences the respondent's utility. If we are calculating the marginal WTP (MWTP) from the status quo level

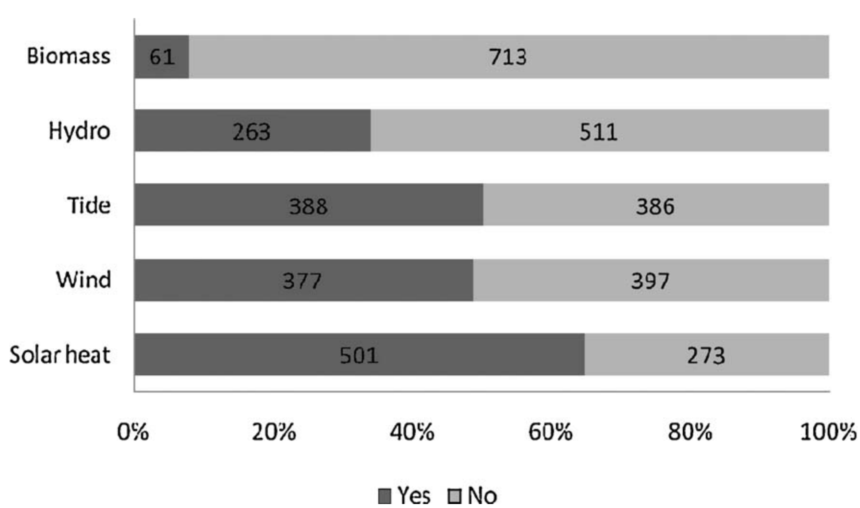

Fig. 4. Public perceptions of various renewable energy sources.

of each attribute and assume that all the other variables remain constant, we can obtain the following MWTP estimates by totally differentiating equation (5) and omitting i for brevity.

$$
\begin{aligned}
\mathrm{MWTP}_{Z_1} &= -\frac{\partial V/\partial Z_1}{\partial V/\partial Z_5} = -\frac{\beta_1}{\beta_5},\\
\mathrm{MWTP}_{Z_2} &= -\frac{\partial V/\partial Z_2}{\partial V/\partial Z_5} = -\frac{\beta_2}{\beta_5},\\
\mathrm{MWTP}_{Z_3} &= -\frac{\partial V/\partial Z_3}{\partial V/\partial Z_5} = -\frac{\beta_3}{\beta_5},\\
\mathrm{MWTP}_{Z_4} &= -\frac{\partial V/\partial Z_4}{\partial V/\partial Z_5} = -\frac{\beta_4}{\beta_5}.
\end{aligned}
\tag{6}
$$

The MWTPs of each attribute represent the marginal rate of substitution between the price and that attribute.

5. The results

5.1. Survey results

A total of 800 person-to-person interviews were conducted for a month beginning May 2006. After missing and inconsistent answers to valuation questions were deleted, 774 responses (96.75%) were found to be valid for further examination for this study, resulting in a total of 4644 (774 × 4) observations. Fig. 4 shows the respondents' perceptions about various renewable energy sources. When we asked whether or not the respondents knew each given renewable energy source, 67.4% of respondents reported knowledge of the process of solar heat power and 48.7%, 50.1%, and 34.0% of respondents reported recognition of the processes of wind, tidal, and hydro power, respectively. Only 7.9% of respondents knew about biomass.

5.2. Estimation results

The estimation results of the MNP model are presented in Table 2. The model was estimated by GHK simulation[2] [13–15]. Using the Wald statistic, the estimated equations are statistically significantly different from zero at the 1% level. Judging from the statistical results, the coefficients on all the attributes are significant, except for Landscape. Moreover, the signs of the coefficients are consistent with our expectation. For instance, the coefficients of Wildlife, Air pollution, and Employment are positive. This means that as the level of any of these attributes increases, the utilities of respondents are increased. On the contrary, the coefficient of the Price attribute is negative and statistically significant: the higher is the price, the lower are the respondents' utilities. However, the coefficient of Landscape is not statistically significant. This does not indicate that respondents derive significant value from the Landscape attribute.

To test whether or not the IIA property holds, a likelihood ratio test is carried out. The likelihood ratio test statistic asymptotically follows a chi-square distribution with one degree of freedom under the null hypothesis that the errors are uncorrelated. When testing for IIA, this study chose 0.10 as the significance level. As a result of the IIA test, we can reject the null hypothesis that the errors are uncorrelated. Since the MNP model does not require the IIA assumption, it is clear that it is an appropriate model for estimating the data of this study.

[2] The drawback of estimating an MNP model is that the model requires the evaluation of multiple integrals for which no closed form solutions exist. Specifically, in the MNP case, for J alternatives, multiple integrals of dimension $J-1$ must be calculated. This is hard and computationally intensive. The GHK simulator makes it possible to approximate the integrals that are required by MNP models. A recent exhaustive survey of probability simulators [19] reached the conclusion that the GHK simulator is the most reliable and accurate way to simulate multivariate normal probabilities for classical estimation [20].

Table 2
Estimation results of the multinomial probit model.

Variable[a]	Coefficient estimate (t-value[c])
ASC_A[b]	0.659** (8.68)
ASC_B[b]	0.554** (7.72)
Landscape	0.001 (0.83)
Wildlife	0.003* (2.31)
Air pollution	0.003** (5.79)
Employment	0.004* (2.29)
Price	−0.0004** (−20.92)
θ_{23}	0.488** (4.14)
θ_{33}	0.456** (6.97)
Number of observations	4644
Log simulated likelihood	−4434.28

[a] The variables are defined in Table 1.
[b] ASC_A and ASC_B refer to alternative-specific constants, which represent dummies for the respondent's choosing the alternatives, A and B, respectively.
[c] * and ** indicate statistical significance at the 5% and 1% levels, respectively.

Table 3
Estimates of the marginal willingness to pay (MWTP) and the confidence intervals for the model.

Attribute	MWTP[a] (t-value[b])	95% confidence interval
Landscape	KRW 2.52 (0.83)	−3.42 to 8.47
	USD 0.0026	−0.0036 to 0.0088
Wildlife	KRW 6.85* (2.32)	1.05 to 12.65
	USD 0.0071	0.0011 to 0.0132
Air pollution	KRW 8.40** (5.81)	5.57 to 11.24
	USD 0.0088	0.058 to 0.0117
Employment	KRW 10.87* (2.29)	1.58 to 20.16
	USD 0.0113	0.0016 to 0.0210

Notes:
[a] The unit is Korean won per month. At the time of the survey, USD 1.0 was approximately equal to 960 Korean won.
[b] The t-values are computed by the use of the delta method. * and ** indicate statistical significance at the 5% and 1% levels, respectively.

5.3. MWTP estimates of each attribute

The results of the MWTP estimates are shown in Table 3. The MWTP for Wildlife is calculated as KRW 6.85 (USD 0.0071) and the t-value is computed as 2.32; thus, we can reject the hypothesis that the value is zero at the 5% level and conclude that the monthly MWTP for Wildlife is different from zero. Next, the households' monthly MWTPs for Air pollution and Employment are KRW 8.40 (USD 0.0088) and KRW 10.87 (USD 0.0113), respectively. According to the Korea Energy Economics Institute [16], the average price of electricity per 1 kWh supplied to households was about KRW 76.43 in 2006. Therefore, the MWTP for wildlife is 9.0% of the price of electricity, and the MWTPs for Air pollution and Employment are 11.0% and 14.2%, respectively, of the price of electricity.

Rather than report only the point estimate, we construct confidence intervals for the point estimate of the MWTP of each attribute in order to allow for uncertainty [17]. To this end, the Monte Carlo simulation technique of [18] was used to generate 95% confidence intervals for the MWTPs. The 95% confidence intervals for the model are also presented in Table 3.

5.4. Scenarios of renewable energy investment

One of the strengths of CE is that the estimated coefficients of the attributes may be used to estimate the WTP for various scenarios in which the attributes can be combined. In other words, the WTP estimates of this study provide preliminary information on the benefits of realistic policy scenarios. In this paper, three different renewable energy policies were considered. Table 4 presents each scenario and the results on households' WTP.

If other conditions are unchanged, households' monthly WTPs for renewable energy investments as in scenarios A, B, and C are approximately KRW 868 (USD 0.9), KRW 1,257 (USD 1.3), and KRW

Table 4
Scenarios of renewable energy investment.

Attribute	Scenario A	Scenario B	Scenario C
Landscape	–	–	–
Wildlife	25% improvement	50% improvement	50% improvement
Air pollution	70% decrease	70% decrease	100% decrease
Employment	10 people	30 people	30 people
WTP (KRW/month)	868.0 (USD 0.9)	1,256.6 (USD 1.3)	1,508.6 (USD 1.6)
WTP (KRW/year)	10,415.4 (USD 10.8)	15,079.2 (USD 15.7)	18,103.2 (USD 18.9)
WTP for all households (KRW billion per year)	77.7	112.5	135.1
(USD million per year)	(81.0)	(117.2)	(140.7)

1,509 (USD 1.6), respectively. During the survey period, the average monthly electric charge was KRW 38,600 (USD 40.2). Therefore, the WTPs under the scenarios considered in this study are between 2% and 4% of the household monthly electric charge. Households' annual WTPs for the renewable energy investments, A, B, and C, are about KRW 10,415 (USD 10.8), KRW 15,079 (USD 15.7), and KRW 18,103 (USD 18.9), respectively.

Furthermore, the annual WTP for all households in the Metropolitan area can be calculated by multiplying the households' annual WTP by the number of households in the Seoul, Incheon, and Gyeonggi. According to the Korea National Statistical Office, there were 7,462,090 households in these areas in 2005. Multiplying this number by the households' annual WTP yields the residents' total WTP in metropolitan areas. The last row of Table 4 shows the total WTP for each scenario. For example, all households in metropolitan areas would be willing to pay KRW 135.1 billion (USD 140.7 million) for the renewable energy plant that has the highest levels of attributes presented in this survey. Compared to a fossil-fuel power plant, this plant will realize a 50% improvement in the diversity of species in the vicinity of the renewable energy plant, a 100% decrease in air pollution, and new, local, long-term employment opportunities for 30 people. Additionally, we can make various scenarios using the attributes that renewable energy investments possess.

6. Concluding remarks

Worldwide, many countries have an interest in renewable energy development for the prevention of climate change and for the sustainable supply of energy. In the case of Korea, the government has set a target that 11% of the total primary energy supply would be obtained by renewable energy sources by 2030 and is considering renewable energy policies that have more practical and substantial effects. Also, the Korean government is trying to increase cooperation with other countries and domestic companies in the development of renewable energy technology. It is making considerable domestic investments to develop these technologies and increase energy efficiency.

This study was motivated by the need for more quantitative information to help policy-makers take appropriate actions with regard to renewable energy investment in Korea. The CE was used to measure the potential value of each attribute in Korean renewable energy investments. An MNP model was employed to relax the assumption of IIA. Overall, the survey was relatively successful in eliciting the MWTP values for renewable energy investment. The respondents' choices for selecting a preferred alternative were found to be within their own abilities. The MWTP estimates were statistically different from zero, except for the Landscape attribute.

The results reveal that the Korean public puts value on the protection of wildlife, reduction of pollution, and increased employment opportunities. On the other hand, respondents do not derive significant value from the improvement of landscapes. The monthly MWTP for a 1% improvement in Wildlife and Air pollution are calculated as KRW 6.85 (USD 0.0071) and KRW 8.40 (USD 0.0088), respectively. The households' monthly WTP for the local, long-term employment of one additional person is KRW 10.87 (USD 0.0113). Also, all households in metropolitan areas would be willing to pay approximately KRW 135.1 billion (USD 140.7 million) for the renewable energy plant that has the highest levels of attributes presented in this survey. Compared to a fossil-fuel power plant, this plant will realize a 50% improvement in the diversity of species in the vicinity of the renewable energy plant, a 100% decrease in air pollution, and new, local, long-term employment opportunities for 30 people.

This study has demonstrated the feasibility of extending the use of CEs to renewable energy investment. From a policy-making perspective, this study provides useful information to help policy-makers develop and implement more appropriate policies to deal with renewable energy investment. In particular, it can be used for the cost–benefit analysis of specific renewable energy investments. Moreover, our study devoted special attention to the use of an MNP model, which is a plausible framework for analyzing the data that were collected from the CE survey without requiring the assumption of IIA. Thus, the study can be a good reference for assessing renewable energy investments.

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